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The Norway maple (*Acer platanoides*) population space location and vital state in the urban park

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Abstract. Urban green spaces are integral to sustainable city development, offering ecological, social, and economic benefits, including climate regulation, biodiversity preservation, and improved human well-being. Among urban trees, the Norway maple (*Acer platanoides*) is widely utilized for landscaping due to its attractive appearance, vibrant autumn foliage, and adaptability to urban conditions. However, its invasive potential raises concerns for native biodiversity. This study explores the spatial distribution, morphometric characteristics, and vitality of *A. platanoides* in the Botanical Garden of the Oles Honchar Dnipro National University. The research employed a quasi-regular sampling grid and recorded 113 specimens, representing 15.5% of the tree population.The study analyzed tree height and trunk diameter, revealing a linear relationship indicative of uniform growth patterns. The trees ranged in height from 4.1 to 28 meters, with taller specimens exhibiting trunk diameters between 45 and 57.3 cm. Morphometric assessments indicated that the most numerous group of trees had a trunk diameter of less than 10 cm, highlighting the prevalence of younger individuals. The vitality assessments based on a 5-point scale showed that 94 trees were in good condition (vitality score of 2), while no trees exhibited signs of severe weakening or decay (scores of 4 or 5). The overall vitality index of 97.6% reflects favorable environmental conditions and the species' ability to thrive in an urban park setting. The Norway maple's ecological resilience is attributed to its tolerance for varied soil conditions, moderate temperatures, and shade. Despite its benefits in urban landscaping, including erosion control and aesthetic contributions, the species presents challenges as a prolific seed producer and an aggressive competitor in disturbed ecosystems. It displaces native flora and alters forest dynamics, necessitating careful management to mitigate its invasive tendencies. This study underscores the dual role of *A. platanoides* as both a valuable component of urban green infrastructure and a potential ecological disruptor. The findings provide insights into the species' adaptability and its implications for biodiversity conservation. Urban planners and ecologists must balance the use of *A. platanoides* in cityscapes with strategies to preserve native species and ecological integrity. Effective measures, such as pruning and selective planting, could enhance its contributions to urban ecosystems while minimizing its negative impacts. By evaluating the ecological and morphological features of *A. platanoides* in a controlled urban environment, this research contributes to a broader understanding of urban tree management. It highlights the need for comprehensive strategies to integrate multifunctional green spaces into urban matrices, ensuring sustainable development and resilience against climate change. The results emphasize the critical importance of monitoring and adaptive management practices to optimize the ecological and social benefits of urban greenery while addressing the challenges posed by invasive species.

Keywords: morphometric parameters; spatial structure; green areas; monitoring; human ecology.

Introduction

Cities have special conditions for plant growth. Urban soils have their own particularities, such as anthropogenic changes initiated by the accumulation of toxic chemicals (Pouyat et al., 2020; Chernyavskaya et al., 2023) and acidity that is shifted towards alkalization due to the snow cover alkalizing because of the salt used to prevent icing in winter. In the warm season, in areas where subterranean utilities are situated, urban soils experience an earlier warming period. This phenomenon promotes an earlier emergence of plants following their winter dormancy. In urban areas, there exists a detrimental effect on growth and development of green spaces is attributed to rising air temperatures, particularly during the summer months, as well as continuous illumination, which alters the phenological phases of various plants species and interfere with the photosynthetic functions of the leaves (O'Riordan et al., 2021; Chernyavskaya et al., 2023). Moreover, urban vegetation experiences drought conditions during summer months, primarily due to insufficient moisture retention in the soil. This phenomenon occurs because precipitation does not accumulate in the compacted soil; instead, it flows into watercourses and drainage systems, thereby bypassing the root zone of the plants. The insufficient availability of optimal water supply and wind processes contribute to reduced air humidity and accelerated depletion of soil moisture, which poses a significant challenge for urban vegetation (Chernyavskaya et al., 2023). In the planning of urban greenery, significant emphasis is placed on the integration of green spaces within the developed areas of a city. The surrounding areas of the city often remain overlooked, resulting in a diminished integrity of the green space system and a lack of rationality in spatial planning. At the same time, urban planning schemes do not correspond to the pace and course of ecological restoration cycles. In addition, the requirement for balanced spatial structures and the location of green spaces between urban development and the natural environment is often ignored (Haaland & van den Bosch, 2015).

Green spaces play an important role in the urban environment. Reducing air pollution, providing shade and habitat for woodland birds, producing oxygen, wind protection, recreational and aesthetic qualities, and architectural applications are the main functions of urban green spaces (Rafiee et al., 2009). Globally, the percentage of people living in cities will increase from 50% in 2010 to almost 70% by 2050 (Mahtta et al., 2022). This will lead to the expansion and densification of urban areas. As migration to cities continues around the world, the need for sustainable urban development is becoming increasingly important. In the urban context, this means creating both resource-efficient systems and good, interesting urban design for attractive cities with a high quality of life. Urban sustainability is associated with the urban form of a compact city (Dempsey, 2010). Urban sprawl can be defined as the development of cities with low density, both residential and commercial, segregated land use, high car use, combined with a lack of public transport, resulting in high demand for land (Johnson, 2001). Related problems are the inefficient use of resources, such as land and energy, which leads to an increased urban footprint, biodiversity loss, environmental problems, and social inequality (Haaland & van den Bosch, 2015). Even urban areas with declining populations (i.e. shrinking cities) can expand in terms of area (Couch et al., 2005). One of the problems identified is the lack of urban green spaces in dense urban areas and the removal of green spaces in the process of urban densification (Fuller & Gaston, 2009; Brunner & Cozens, 2013). The advantages of urban green spaces encompass a variety of aspects, including physical and psychological well-being, social cohesion, and the provision of ecosystem services (Chang et al., 2017). Urban green spaces are quite diverse and can be categorized based on various factors, including their size, intended purpose, types of vegetation cover, and proximity to public transportation and other amenities (Sister et al., 2010; Wolch et al., 2014). Public green spaces include: parks, sports grounds, community gardens, nature reserves, and protected areas; green paths and trails, urban trees, as well as the banks of streams and river banks; other less conventional environments, such as green walls, cemeteries, green alleys. Private green spaces encompass backyard gardens and the surrounding areas of apartment buildings, as well as corporate campuses (Roy et al., 2012; Wolch et al., 2014).

Researchers highlight that the distribution of green spaces is frequently unequal among different segments of society. Access to these green spaces may be stratified according to factors such as income, age, gender, and ability. This phenomenon is referred to as environmental injustice, a topic that has been the focus of extensive scholarly research (Bick et al., 2018; Givens et al., 2019). Typically, individuals from low-income backgrounds reside in urban centers or inner-ring suburbs, where the landscape is often inadequately maintained or poorly developed. In contrast, wealthier residents tend to inhabit suburban peripheries characterized by abundant greenery. This environmental inequity has been acknowledged in urban planning, resulting in the implementation of park development programs and various greening strategies aimed at enhancing the quality of life in economically disadvantaged areas. However, the expansion of well-maintained green spaces in these neighborhoods may give rise to an urban green paradox. As the quality and quantity of green space improve, the attractiveness of these areas increases, consequently elevating housing values. This escalation in housing costs has the potential to trigger gentrification, which may lead to the displacement of residents for whom the green spaces were originally intended. Continuous urban growth has resulted in a myriad of environmental challenges, particularly concerning air, water, and noise pollution. The phenomenon of uncontrolled urban sprawl, coupled with the disorganized integration of urban and rural areas, contributes to the inadequacy of urban infrastructure in suburban regions. This inadequacy, in turn, leads to an escalation of traffic flows towards areas where infrastructure is already saturated. To manage urban growth effectively, urban planners implement various strategies for the arrangement of green spaces. In Europe, different models of urban green landscapes can be positioned along a continuum between two extreme scenarios: one designed to limit the encroachment of cities into adjacent rural areas, and the other aimed at organizing urban space to facilitate future development and expansion. By contrast, the traditional configuration of urban green spaces may differ on other continents. For instance, in East Asia, urban and rural areas have historically coexisted in close proximity to one another. In this context, agricultural enterprises and forested landscapes serve as visual amenities and cultural services even in modern megacities (Yokohari et al., 2000). So-called green belts are popular in Europe. The idea of green belts originated in E. Howard's popular garden city model. According to E. Howard, the horizontal spread of garden cities should be strictly limited to the surrounding green belt, which is a space designated for agricultural and recreational purposes. The concept of the green belt is predominantly linked to British urban development policy following the Second World War, specifically the New Towns initiative. Throughout various phases of its implementation, new settlements were established with the objective of alleviating population density, initially in London and Glasgow, and subsequently in cities such as Liverpool, Birmingham, Manchester, and other major urban centers. Rather than adhering to the conventional peripheral expansion of urban areas along transportation corridors, these new settlements were developed approximately 50 km away from the metropolitan hubs. They were initially equipped with comprehensive infrastructure and housing, and were distinctly separated from the megacities by a robust green belt. Overall, the effectiveness of the New Towns policy can be attributed not solely to the prohibition of megacity expansion, but also to broader trends toward decentralization and deconcentration that coincided with this initiative. Since the 2000s, new cities under the programme in the UK have been created on the principles of ecopolises. The green belt approach has been implemented in several cities across France, Spain, Austria, and Hungary. Originally, the primary function of green belts was seen as controlling urban growth, preventing conurbation (agglomeration), and separating urban and rural functions. The latest arguments in support of green belts focus on nature protection and the preservation of undeveloped areas (Kühn, 2003).

The greenbelt approach has certain drawbacks that force urban planners to look for alternatives. The key disadvantages of green zones include: increased inequality between residents within the green zone and those outside it; lack of accessibility to the general public or lack of scenic beauty; constraining urban growth, leading to higher average property prices and limiting economic development; increased commuting distances for residents outside the outer boundary of the green zone; and deterioration of the quality of the inner green zone due to lack of land management. There are several solutions to avoid the above disadvantages of green zones. The initial alternative involves the continuity of green spaces to facilitate regulated urban movement along designated pathways, which are initially equipped with suitable infrastructure for residents situated beyond the primary urban perimeter. A pertinent example of such a green space is the network of regional parks surrounding Berlin. It is important to emphasize, however, that these regional parks do not conform to the traditional definitions of public parks or nature reserves, as they are considerably expansive (ranging 144 to 964 km^2) and are generally regarded as rural areas (Kühn, 2003). In contrast to green belts, green wedges ensure that green areas are permanently connected to neighbouring urban areas, providing space for recreational activities, sports, educational purposes, air quality improvement, water management, sustainable transportation, and nature conservation. An essential characteristic of green wedges is their capacity to extend along urban growth corridors, thereby promoting the sustainability of green spaces. The aforementioned cases illustrate the role of green spaces as temporary measures or buffers within urban environments, contributing to the alleviation of pressure on property prices. Green spaces play a significant role in urban development; however, they also fulfill an integrative function. As open space structures, these areas have the potential to unite diverse communities. A notable example of an integrative green center is the Randstad urban region in the Netherlands, which comprises an agglomeration of four major cities: Amsterdam, Rotterdam, Utrecht, and The Hague. The Randstad is an example of an urbanised belt around a green core (the latter known as the “Green Heart”). The Green Heart is a predominantly agricultural area, usually used for pasture. The region encompasses an area of approximately 1,500 km^2 and comprises 70 local municipalities; however, population growth in this area has been influenced by indirect constraints. The proportion of recreation and nature conservation areas is rather low. Thus, Randstad is an example of a regional city that is constrained from the periphery to the center. By contrast, the Green Heart functions as both a barrier and a facilitator of urban growth (Kühn, 2003). Above, we have discussed mainly large green spaces that influence the overall landscape of the city and the countryside. However, there are also other types of green spaces that influence urban planning. The most common of these are green corridors and green infrastructure. Green corridors form a linear natural network that connects different urban areas or green spaces. Despite their relatively limited dimensions, green corridors can serve several functions typically associated with larger green spaces, including the mitigation of pollution and noise, the promotion of physical activity, and the encouragement of public transport usage, increased social interaction, protection from high temperatures and strong winds, and biodiversity in the city. Green infrastructure issues are crucial to the planning regime of a compact city. The main idea of a compact city is to abandon classical urban zoning and provide for the multifunctional use of land plots to enhance social cohesion and decrease the prevalence of car ownership. In this case, the lowest density for residential development should range from 40 to 80 units of 2 to 4-story buildings per hectare. Such residential development should be situated around nodes that integrate structural elements of employment, education, trade, and recreation to maximise local interaction. However, the compact city model does not leave enough space for green areas in the inner city. Green infrastructure should be moved to the outer boundaries of districts, creating small green belts for inner-city areas.

In 2008–2014, the compact city model was applied to 13 of Norway's largest cities as part of a city revitalisation strategy. Green space distribution varies significantly among urban areas; however, there is limited understanding of the factors and geographical patterns that contribute to these disparities. This knowledge is crucial as urbanization is progressing at an accelerated pace, and the implications for green spaces are not yet fully understood. Fuller & Gaston (2009), who examined the 386 European cities, found that the area of green space is growing faster than the city area, but decreases only slightly with increasing population density. Thus, the provision of green spaces in a city is first of all associated with the city's area rather than the number of residents they serve or simply filling space. Consequently, compact cities (small in size and with a high population density) demonstrate that provision of green space per capita is notably insufficient. At elevated levels of urbanization, the network of green spaces demonstrates resilience to additional urban densification. As urban areas expand, the relationship between individuals and the natural environment becomes increasingly contingent upon the quality of landscapes that extend beyond established green space networks, including elements such as street trees, as well as the size, composition, and management of residential gardens and allotments (Fuller & Gaston, 2009). Despite a large body of empirical evidence highlighting the importance of urban landscapes for improving quality of life, the scientific literature examining the impact of urban consolidation on vegetation and trees remains limited. Researchers often find an overwhelming tendency toward destruction of all greenery when redeveloping land plots as part of current urban consolidation policies. It is well known that urban vegetation and trees are extremely important as a significant and valuable part of the 'green space' in urban areas. However, developers have virtually no incentives to preserve existing urban vegetation and trees, and there are limited opportunities to regulate the protection of existing green spaces in private ownership. Urban green space is defined as vegetation present within the urban environment, encompassing parks, open spaces, residential gardens, and street trees (Brunner and Cozens, 2013). The planning and management of urban green spaces is a key issue in the context of the compact city concept, as these spaces provide significant benefits to city residents (Pauleit, 2003; Tzoulas et al., 2007), and is also an important habitat for wildlife (Goddard et al., 2010). To improve the quality of human life in cities and to preserve biodiversity, the issue of creating more allotment plots is being considered (Galluzzi et al., 2010). The definition of the concept of 'homestead' varies in the literature. Often it is defined as a private space adjacent to a dwelling that may contain grass at various levels, ornamental and edible vegetation, water sources, pathsб and sometimes temporary structures such as greenhouses. It can also be simply defined as the area left after the construction of a privately owned house (Smith et al., 2006). However, it is worth emphasising that allotments are different from isolated patches of vegetation, such as forests, because they are managed on an individual scale and because, although fragmented, they form a significant extension of the surrounding area. Although backyard landscapes are obviously too small to be biologically significant when considered as a whole in urban areas, they reach significant sizes, often exceeding the area of garden squares and city parks (Gaston et al., 2005; Loram et al., 2007b; Marco et al., 2008).

Studies on biodiversity in urban parks and gardens have recognised the potential value of garden flora for biodiversity (Hermy & Cornelis, 2000; Smith et al., 2006). It plays a key role in urban ecological dynamics and, in particular, in creating pools of species that temporarily use, colonise, or persist in urban areas. Indeed, garden species fulfil vital primary needs of urban wildlife in providing important habitats (Chamberlain et al., 2004; French et al., 2005) and resources, as well as in modifying the microclimate (Jo & McPherson, 2001). However, the impact of garden flora on wildlife is not always positive. Most garden species that have been introduced into green spaces are exotic, and some of them can avoid cultivation, take root and become part of the natural vegetation through naturalization (Sukopp, 2004; McDougall et al., 2005). They can have a negative impact on our semi-natural and artificial ecosystems by becoming invasive. Horticultural flora is therefore a major source of alien plant introductions, which is currently considered one of the greatest threats to biodiversity (Sax & Gaines, 2003). In addition to the risk of invasion, these new species can also breed with spontaneous species, leading to a loss of genetic variability in the local flora (Poff et al., 2007; Marco et al., 2008). The widespread practice of creating hybrids in horticulture and plant breeding poses additional risks to native plants, as these artificial hybrids can become a bridge for gene transfer between two previously intersterile species.

The importance of private gardens for biodiversity conservation (including the conservation of endangered species) is increasingly recognised, but there have been few attempts to describe the composition and distribution of biodiversity in these areas (Gaston et al., 2005; Thompson et al., 2005; Loram et al., 2007b; Marco et al., 2008; Davies et al., 2009; Beumer & Martens, 2015). Clearly, the potential for greening backyard gardens needs to be further explored. However, a preliminary literature review shows that private green spaces are strategic locations for increasing vegetation cover in urban areas and, consequently, for increasing their ecosystem services. At the same time, tree planting is the best way to increase the number of a wide range of invertebrate and vertebrate taxa in urban yards (Smith et al., 2006; Loram et al., 2007a). In addition, wildlife living in trees are more protected from predation by domestic animals such as cats (Thomas et al., 2014). Thus, successful planning of urban courtyards is only possible on the basis of preliminary research that will provide insights into the environmental, cultural and socio-economic factors that influence the configuration of these courtyards.Gardens tend to have an ecologically unusual structure and plant diversity (Strayer et al., 2003; Thompson et al., 2005; Smith et al., 2006). Not only are most species not native, but they are also found in extremely small numbers (often only a single plant), a result of many gardeners' desire for high floristic diversity. There are good reasons to advocate for more native species to be grown, for example, they are more likely to provide resources suitable for native plant-feeding invertebrate species. In addition, many invasive plant species originate from gardens, and even more may spread beyond the garden, given the opportunities provided by climate change. However, this should not mean that gardens with few native plants are not valuable for local wildlife. Gardens with few native plant species can be just as rich in invertebrates as gardens with many native plants (Thompson et al., 2005; Smith et al., 2006). One of the reasons for this is that the vast majority of garden animals are predators, parasitoids, detritivores or pollinators that are not dependent on specific plant species. On the other hand, many garden herbivores are generalists, ready to consume a wide range of different plants. This means that in the average urban garden, even native herbivores that are restricted to one plant genus may find their needs met by alien plants. Finally, some alien plant species can provide positive benefits to some invertebrates, for example by extending flowering seasons. As with the provision of three-dimensional complexity, ensuring a diversity of plants is generally more important than whether these species are native or alien in origin. Gardens are relatively poorly understood compared with many "natural" vegetation types, but all evidence points to their potential importance as a major resource for wildlife in cities (Thompson et al., 2005). Urban forests also play a very important role in landscaping. Different types of forests can first be differentiated on the basis of their location in relation to urban areas. According to this spatial approach, urban forests can be distinguished from peri-urban and non-urban forests. Urban forests can be completely surrounded by built-up areas and thus represent forested "islands" within urban areas. More often, however, they are located on the outskirts of the city and maintain direct connections with developed urban areas on one side and with the open landscape on the other. Peri-urban forests are situated in close proximity to urban areas and are intricately integrated into the peri-urban cultural landscape. Historically, many of these landscapes were predominantly influenced by agricultural practices or rural lifestyles; however, they are currently experiencing significant pressures from suburbanization. By contrast, non-urban forests are located at a considerable distance from urban centers and are primarily associated with components of the usual landscape of culture.

This spatial organization typically aligns with the various functions of forests. As the proximity to the city increases, forests become more accessible for urban residents, and thus the social function of forests increases (Kowarik, 2005). The ecological function of forests, particularly concerning traditional timber and hunting resources, is diminishing to a similar degree. However, it would be imprudent to start with the assumption that ecological functions are being replaced by social functions in prohibited forests. It is increasingly evident that social and ecological functions, commonly referred to as 'ecosystem services,' can also possess intrinsic value (Tyrväinen, 2001; Kowarik, 2005). Among all the different types of forest vegetation in cities, the most common are stands with forest characteristics that can be formed as a result of large-scale tree planting in park areas, as well as street trees and regeneration plantings. The stands are defined based on functional objectives, with artistic and aesthetic considerations often informing their design and maintenance. As a result, the forests that emerge from urban greening are significantly influenced by cultural factors. An additional feature of this type of forest is significant species abundance and the large role of non-native species in urban green spaces (Jim & Liu, 2001; Kowarik, 2005). Native species are also often genetically distinct from regional indigenous plants, as they are scattered across a supra-regional network of nurseries that largely imports seed material from other, more distant areas.

Despite their cultural basis, urban green-space forests can also be largely influenced by natural factors. The natural regeneration of tree species and the establishment of wild plants within plantations are significant factors to consider. Additionally, the phenomenon of planted species 'escaping' from cultivated plantations contributes to this dynamic. Consequently, the likelihood of a species becoming naturalized is directly correlated with the number of communities established (Rejmánek, 2000). A striking example of this is the widespread of Norway maple (*A. platanoides*, *A. pseudoplatanus*) from horticultural plantations (Kowarik, 2005). The interplay between cultural practices, such as cultivation, and natural processes, including the establishment and dissemination of cultivated species, frequently results in the development of distinct plant communities within urban green spaces. This phenomenon is particularly evident in historic gardens, where numerous plant species that were cultivated during the Baroque or landscape gardening periods have persisted and, in some instances, established substantial populations. These species may be regarded as cultural remnants or as indicators of previous horticultural practices. Furthermore, in the context of urban greening, woodlands may also emerge through the transformation of virgin forests or woodlands that have been utilized for forestry purposes. In summary, urban forestry is an integrated, city-wide approach to planting, caring for and managing trees in a city to provide multiple environmental and social benefits to its inhabitants. It is the art, science, and technology involved in the management of trees and forest resources in the community and surrounding ecosystems to provide the residents with the psychological, sociological, aesthetic, economic, and environmental benefits (Konijnendijk, 2004). Trees are the most effective and inexpensive solution to a range of urban problems, such as air quality, water quality, groundwater recharge, stormwater retention, reducing urban heat islands, increasing building efficiency, improving health, encouraging walking and cycling, improving safety, boosting the economy, and adding beauty and aesthetics (Konijnendijk, 2003).

The multifunctionality of green spaces is frequently highlighted in relation to cultural heritage, recreation, aesthetics and numerous other social and ecological functions (Pauleit, 2003; Mell, 2009). It is noted that urban renewal cannot be successful without the gradual integration of multifunctional green spaces into the urban matrix, which is insufficient in most industrial cities of the world. Green infrastructure can play a key role in urban regeneration by providing an additional green matrix of spaces that offer multiple benefits to the human population. Green infrastructure can also be seen as a sink for natural resources, helping to control urban climate, manage water resources, and provide important green networks in urban areas. Due to the potential of green infrastructure to be 'retrofitted' in most environments, green infrastructure can be implemented in a variety of urban environments to promote sustainable community development and landscape management. The wider climate control and economic regeneration benefits of integrating green infrastructure can, in the long term, underpin further urban regeneration (Mell, 2009). Many of the functions of green spaces that are considered important for sustainable urban development have to be realised in a limited space (Baycan-Levent & Nijkamp, 2009). Despite the diversity of green space policies in European cities, four factors/attributes are critical to the success of urban green space planning and management: the share of green space in urban land use; changes in this share over time; the intensity of city administration involvement; and the degree of citizen participation (Baycan-Levent & Nijkamp, 2009; Baycan & Nijkamp, 2012). To date, the growing crisis related to climate change and global warming has led to global concern and a search for best practices in urban green space management. Along with the new concept of a 'smart green city', both governmental and non-governmental organisations continue to advocate for multidisciplinary technical and non-technical efforts to adopt new design frameworks to transform new cities into qualitatively new and different ones. The plan supports the new implementation of urban green space management practices. In order to accelerate the process of creating sustainable cities and improve the relationship between people and the environment to build a sustainable future, it is necessary to continue cooperation among different parties, pay special attention to the international level and implement a large number of supporting policies (Tate et al., 2024). As urban sprawl can threaten rural areas, densification processes in cities and towns can potentially threaten urban green spaces. There is evidence that urban green spaces are under pressure from densification processes, such as infill development (Stephan Pauleit et al., 2005; Rafiee et al., 2009; Byomkesh et al., 2012). There is a lack of information on the environmental impacts of urban change and the dynamics of green spaces. Such information is needed to better understand the sustainability of urban development processes, both planned and unplanned. In recent decades, urban areas have been changing rapidly, leading to the fragmentation of green spaces and the deterioration and dysfunction of these important elements of any city. The results of many studies show that the decline in the overall quality of life of city residents is associated with the consequences of this phenomenon (Rafiee et al., 2009). The study of land use and vegetation changes using aerial photographs and the link between these changes and the socio-economic status of the areas revealed a loss of green space in all the study areas. It was found that wealthier areas with low population density lost more green space, especially tree cover. The main reason for this was development, which resulted in the demolition of gardens. However, green spaces were also lost in already densely built-up, depressed areas due to the reuse of abandoned land. As a result, the models used in the study predicted negative environmental impacts for all districts. The findings highlight the need to critically rethink concepts such as urban densification and to place greater emphasis on the conservation and management of urban green spaces (Stephan Pauleit et al., 2005).

To optimise greening, it is important to clarify the species range of trees that can be successfully grown in urban areas. Globally, maples are considered one of the most important tree groups for urban forests, as well as for lawns, streets and parks. Recent research suggests that maples may be a keystone species, meaning that they play a disproportionately important role in shaping and maintaining their ecosystems, and in increasing local species diversity. History shows that maples are also a fundamental species for humans and have played a vital role in the structure of societies around the world (Matkovska et al., 2019). The objective of this research was assessing the success of Norway maple planting in urban parks based on its spatial structure and vitality.

Materials and methods

The study on the vital status of Norway maple (*Acer platanoides* L.) took place in the territory of park zone of the Oles Honchar Dnipro National University Botanical Garden in September–October 2023. The points of plant measurement were arranged in a quasi-regular network, with a distance of 14.0 ± 0.28 m between points, ranging 7.1 to 31.0 m. The coordinates of the sampling points were recorded using a mobile GPS device. A total of 113 Norway maple trees were documented. We also measured the height and diameter of tree trunks and assessed their vital condition.

The height of the trees was assessed using a Suunto PM-5 mechanical height meter, with three measurements taken for each plant. The average height was then calculated based on these values. Tree diameters were measured using a tree caliper, which is defined as the distance between two parallel tangents. The vital status of the trees was assessed using a 5-point scale developed by Alekseev (1989). The index of tree damage was computed by the following formula:

$$L_n = \frac{100n_1 + 70n_2 + 40n_3 + 5n_4}{N},$$

where Lnis the relative vital status of the examined stand; n1is the number of trees evaluated as healthy; n_2 is the number of trees estimated as weak; n_3 is the number of trees estimated as being severely weakened; n_4 is number of trees identified as dying; N is the total number of trees recorded in the sample area (including deadwood). The trees were classified as "healthy" if their vital status index was 90–100%,", "healthy with signs of weakening" if it equaled 80–89%, "weakened" if the index accounted for 70–79%, "damaged" if it was 50–69%, "severely damaged" in case of 20–49%, and "destroyed" when the index value was of less than 20% (Chongova et al., 2022).

The soil moisture content was measured using an MG-44 soil moisture meter (Ukraine), with readings taken at a depth of 5–7 cm. This device has a measurement resolution of 0.1% and an associated error margin of 1%. The soil temperature within the 7–10 cm layer was assessed using a digital thermometer (TC-3M, Ukraine). The air temperature and atmospheric humidity at a height of 1.5 m were recorded with a Huato HE-173 temperature and humidity logger (China). Illuminance at the same height was measured using an RSE–174 lux meter (Germany). The electrical conductivity of the soil was measured in situ using an HI 76305 sensor

(Hanna Instruments, Woonsocket, RI), which operates in conjunction with a portable HI 993310 tester. This instrument is designed to assess the total electrical conductivity of the soil, defined as the cumulative conductivity contributed by air, water, and soil particles. The results obtained from this device are reported in units of soil salt concentration, expressed in grams per liter. When comparing the data yielded using HI 76305 with laboratory data we are able to obtain the coefficient of conversion units, which is 1 dS/m = 155 mg/L (Pennisi & van Iersel, 2002; Yorkina et al., 2021). The data on the environmental properties were subjected to principal component analysis.

The crown cover of the tree stand (hereafter referred to as "the Cover") was evaluated through visual inspection, with the results expressed as percentages. The canopy structure and gap light transmission indices were derived from true-color fisheye photographs using Gap Light Analysis software. Hemispherical smartphone photography allowed us to make a swift assessment of the forest canopy and light regime. This method serves as a suitable alternative to traditional camera-based hemispherical photography, providing comparable results in a more efficient and cost-effective manner (Bianchi et al., 2017). We evaluated indices such as canopy openness and Leaf Area Index. Canopy openness, which is expressed as a percentage, indicates the proportion of the open sky visible beneath the forest canopy. This index is calculated exclusively from a hemispherical photograph and does not account for the influence of the surrounding topography. The Leaf Area Index (LAI) represents the effective leaf area integrated over zenith angles ranging from 0° to 60° (Stenberg et al., 1994). Direct Transparency refers to the amount of direct solar radiation transmitted through the canopy, measured in moles per square meter per day (mol/m²/day). Diffuse Transparency denotes the amount of diffuse solar radiation transmitted by the canopy, also measured in moles per square meter per day (mol/m²/day). Total Transparency (Trans) is the sum of both direct and diffuse transparency, expressed in moles per square meter per day (mol/m²/day).

Results

The Norway maple is phanerophyte, megatroph, capable of withstanding high levels of humidity, necessitates moderate ambient temperatures, prefers shaded environments, is pollinated by insects (entomophilous), and is dispersed by wind (anemochorous) in forested areas (sylvatic plant). It is native to Europe. A total of 113 Norway maple (*Acer platanoides*) individuals were documented within the research area, representing 15.5% of the overall tree population across all species. The distribution of Norway maple is not uniform, as these trees predominantly inhabit the central part of the research.

The analysis of the Norway maple trees in the research area, based on trunk height, revealed a nearly equal ratio of low (up to 8 m) and tall (from 16.1 to 24 m) specimens. The most numerous groups were those with trunk heights ranging 4.1 to 8 m and 16.1 to 20 m, comprising 24 and 23 individuals, respectively. The group of trees with the tallest trunks (24.1 to 28 m) included 8 individuals. The most numerous group, consisting of 41 trees, included the thinnest plants in the population, each with a trunk diameter of less than 10 cm. The subsequent size groups are nearly equal in number, with only 6 plants exhibiting a trunk diameter greater than 50 cm.

The height and trunk diameter of the studied representatives of *Acer platanoides* exhibited a predominantly linear relationship; as the height of the plant increases, the diameter of its trunk also increases. Among the recorded specimens of the Norway maple, those exceeding 25 m in height typically have trunk diameters ranging from 45 to 57.3 cm, while the shortest specimens, measuring up to 5 m, have trunk diameters of up to 5 cm. The tallest recorded plant, standing at 28 m, also had the largest trunk diameter of 57.3 cm.

The vast majority of plants of the species, i.e. 94 representatives, were characterized by a vital status score of 2, indicating good condition. This group exhibits the greatest variability in morphometric parameters. A nearly equal number of plants received vital signs of 1 (healthy trees) and 3 (satisfactory condition of trees), with 10 and 9 plants, respectively. Plants with a vigour score of 1 demonstrated the highest values for trunk height and diameter, along with relatively low variability. No plants with vigour scores of 4 or 5 were recorded in the study area. The total vital state index of the studied population of Norway maple in the DNU Botanical Garden park zone was 97.6%, indicating that the plants are healthy. This suggests that the examined plants are thriving in favorable environmental conditions, which aligns with previous research identifying *A. platanoides* as a mechanically stable species in urban environments (Kornienko et al., 2019).

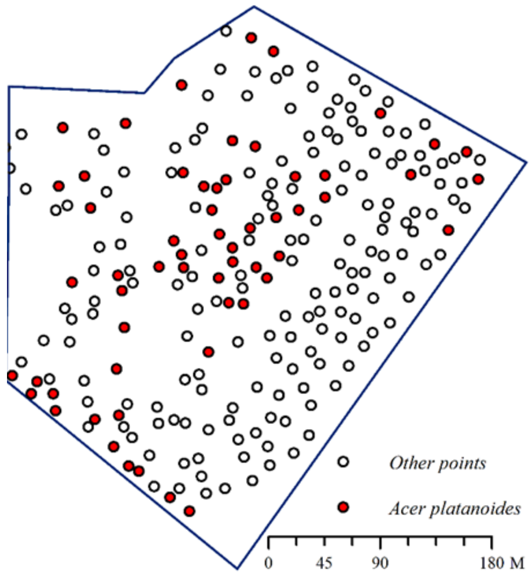

Fig. 1. *Acer platanoides* space location in the park zone of the Oles Honchar DNU Botanical Garden

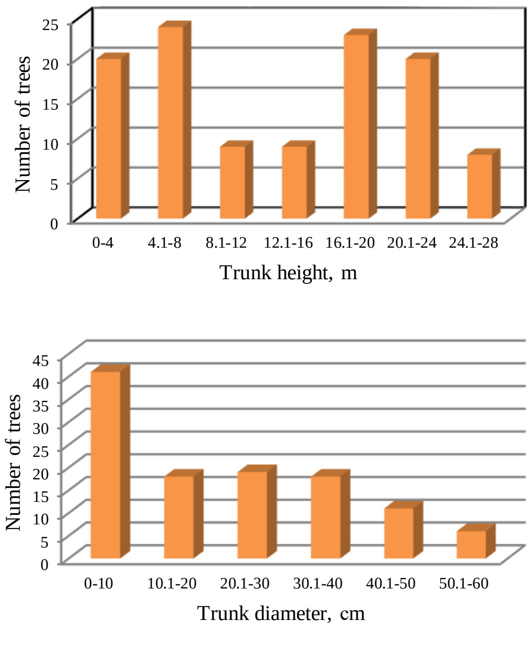

Fig. 2. Distributionof *A. platanoides* by height (*a*) and trunk diameter (*b*): the abscissa axis is the size class of trees by stem height (m) and trunk diameter (cm); the ordinate axis is the number of trees in the respective size classes

Table 1
The morphometric parameters of *A. platanoides* in relation to vital status

Vital status	The number of individuals	Height, m	Diameter, cm
1	10	20.5 ± 4.2	35.2 ± 12.6
2	94	12.3 ± 8.2	18.3 ± 15.8
3	9	17.0 ± 5.9	28.1 ± 14.3

The relationship between the height and diameter of *A. platanoides* plants at various developmental stages is characterized by linear regression analysis. As the height of the tree trunk increases, there is a corresponding increase in its diameter. However, this relationship is only reliable for trees classified as vital stages 1 and 2, which were the most prevalent in the study area ($P = 0.012$ and $P < 0.001$, respectively). For plants with a vital status of 3, the relationship between height and trunk diameter is not significant ($P = 0.136$), although a linear trend between the two variables is still evident.

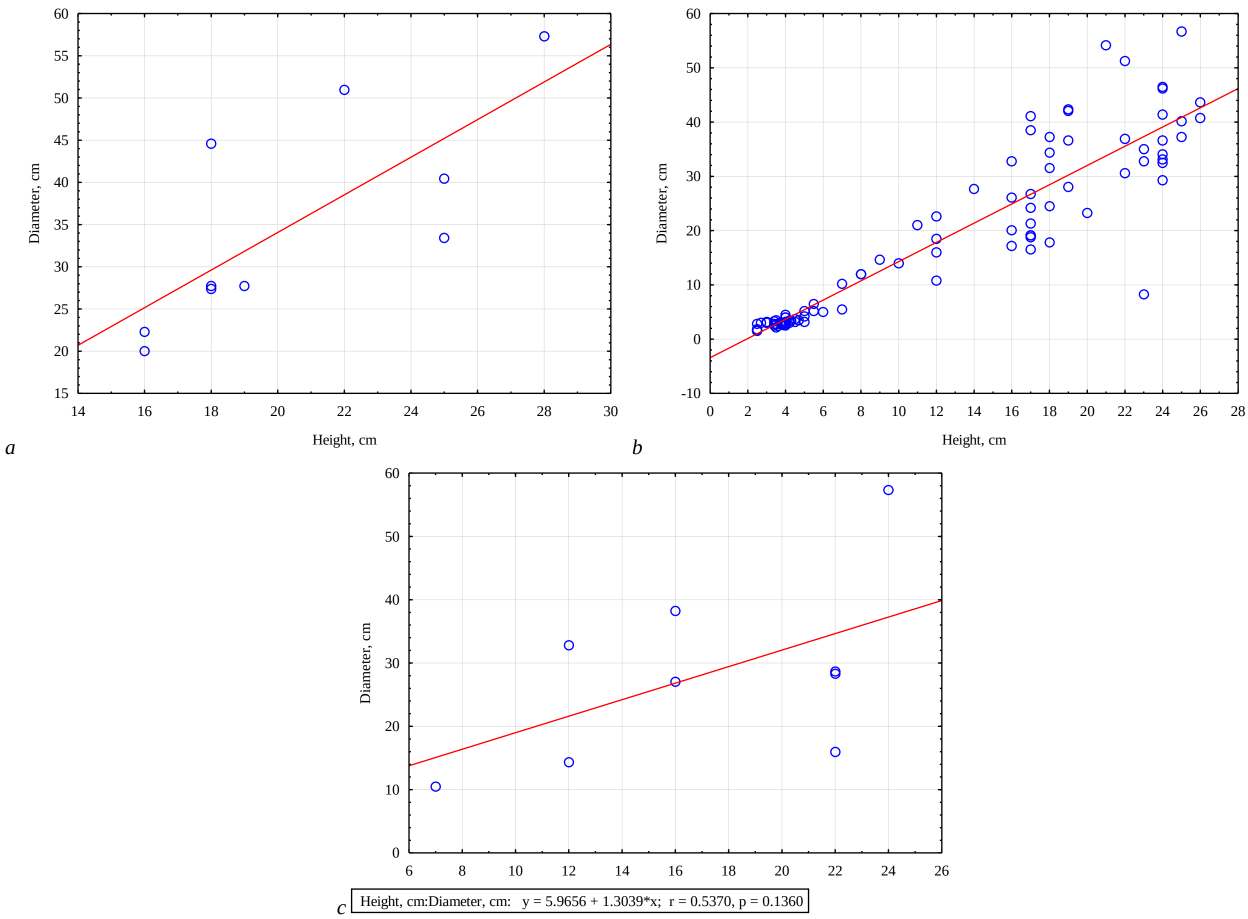

Fig. 3. The correlation between height and diameter of the *A. platanoides* trees of varying vital states: *a* is the vital state 2 (Y = –10.51 + 2.22*X; r = 0.75, P< 0.001); *b* is the vital state 3 (Y = –3.42 + 1.77*X; r = 0.91, P < 0.001); *c* is the vital state 4 (Y = 5.96 + 1.30*X; r = 0.54, P = 0.14)

The environmental properties of the park, specifically in areas with and without the presence of *A. platanoides*, exhibited notable variations (Table 2). The index values were similar across the park, with areas having *A. platanoides* presence showing slightly higher values (6.1 ± 0.8) compared with the general park communities (6.0 ± 1.1), suggesting marginally wetter conditions. Soil temperature remained consistent in both areas, averaging 1.5 °C (log-transformed), indicating no significant variation. Similar soil moisture levels were observed (1.1 ± 0.2, log-transformed), suggesting uniform hydration across the habitats. Soil electrical conductivity was consistent at 0.2 ± 0.1 dSm/m, implying stable ionic activity in the soil. The *A. platanoides* areas exhibited lower air temperatures (28.9 ± 3.2 °C) and higher humidity (50.1 ± 14.5%) than the general park communities (31.2 ± 3.9 °C and 43.0 ± 13.9%). The light levels were significantly reduced in *A. platanoides* areas (13.2 ± 16.6 KLc) compared with the general communities (23.5 ± 21.0 KLc), likely due to increased canopy cover. The areas with *A. platanoides* were observed to have denser canopy coverage (0.7 ± 0.1%) and reduced canopy openness (26.7 ± 14.0%) relative to the general park communities (0.6 ± 0.2% cover, 39.1 ± 20.9% openness). The grass cover was lower in *A. platanoides* zones (38.6 ± 25.8%) compared with the park average (51.7 ± 23.6%), though grass height remained similar at 1.6 cm (log-transformed). The areas with *A. platanoides* exhibited a higher leaf area index (2.3 ± 0.9) than the general park communities (1.6 ± 0.9), contributing to reduced transparency levels for both direct and diffuse light. The total transparency was lower in the *A. platanoides* areas (6.2 ± 3.8) compared with the general park communities (9.3 ± 6.1). These findings highlight how the presence of *A. platanoides* influences environmental variables, such as increased canopy density, reduced light penetration, and localized microclimatic changes, including cooler air temperatures, and higher humidity. Such dynamics underscore the species' role in shaping its surrounding habitat.

Table 2

Descriptive statistics of the variability of ecological properties within the park and in areas where *A. platanoides* is present (mean ± SD, N = 230)

Variable	Park planation	Park planationwith *A. platanoides* presence	*F*-ratio	*P*-value
Topographic wetness index	6.0 ± 1.1	6.1 ± 0.8	4.0	0.05
Soil temperature,°C (log transformed)	1.5 ± 0.1	1.5 ± 0.1	34.7	<0.001
Soil moisture, % (log transformed)	1.1 ± 0.2	1.1 ± 0.2	11.3	<0.001
Soil electrical conductivity, dSm/m	0.2 ± 0.1	0.2 ± 0.1	13.3	<0.001
Lighting, KLc	23.5 ± 21.0	13.2 ± 16.6	44.7	<0.001
Air temperature,°C	31.2 ± 3.9	28.9 ± 3.2	50.2	<0.001
Air humidity,%	43.0 ± 13.9	50.1 ± 14.5	34.9	<0.001
Canopy cover, %	0.6 ± 0.2	0.7 ± 0.1	48.6	<0.001
Grass height, cm (log transformed)	1.6 ± 0.3	1.6 ± 0.3	6.8	<0.001
Grass cover, %	51.7 ± 23.6	38.6 ± 25.8	30.3	<0.001
Canopy openness, %	39.1 ± 20.9	26.7 ± 14.0	70.6	<0.001
Site openness, %	32.3 ± 20.1	22.1 ± 12.2	65.6	<0.001
Leaf area index	1.6 ± 0.9	2.3 ± 0.9	88.9	<0.001
Transparency direct	4.7 ± 3.3	3.2 ± 2.2	40.5	<0.001
Transparency diffuse	4.6 ± 3.0	3.0 ± 1.8	63.7	<0.001
Transparency total	9.3 ± 6.1	6.2 ± 3.8	55.8	<0.001

The areas with *A. platanoides* had lower air temperatures than the general park zones. The dense canopy provides shade, reducing heat stress, especially during summer. The increased air humidity (50.1 ± 14.5% compared with 43.0 ± 13.9%) may enhance thermal comfort for visitors, particularly in dry climates. The increased canopy cover (0.7 ± 0.1% compared with 0.6 ± 0.2%) and reduced canopy openness (26.7 ± 14.0% versus 39.1 ± 20.9%) create a lush, forest-like atmosphere. This enhances the visual appeal, making the park more inviting for activities like walking and relaxation. *Acer platanoides* is known for its vibrant autumn foliage, which could enrich the park's visual appeal during fall, attracting more visitors. The lower ligh levels in the *A. platanoides* areas (13.2 ± 16.6 vs. 23.5 ± 21.0 KLc) may create cooler, shaded spots that are ideal for picnics and resting. However, reduced light could also feel overly dim in some areas, potentially limiting visibility or creating less welcoming spaces during overcast days. The lower grass cover in *A. platanoides* areas (38.6 ± 25.8%) might reduce open spaces for sitting or recreational activities on lawns. However, visitors may prefer these areas for pathways or shaded benches. Higher leaf area indices (2.3 ± 0.9 compared with 1.6 ± 0.9) suggest denser foliage, which could obstruct views or create a sense of enclosure, impacting how visitors perceive safety or accessibility. Dense canopies and reduced site openness may buffer urban noise, creating a quieter and more tranquil environment. This setting is conducive to relaxation and stress relief. Shaded areas and lush greenery have well-documented positive effects on mental well-being, making the park more attractive for activities like meditation or casual walks. Visitors seeking sunlight might find areas dominated by *A. platanoides* less suitable due to reduced canopy openness and lower site transparency. Increased air humidity might feel uncomfortable for some visitors, especially during humid seasons. *Acer platanoides* can outcomplete native species, potentially reducing the diversity of flora and fauna, which might impact visitors interested in ecological or educational experiences. The presence of *A. platanoides* transforms the park into a cooler, shaded, and quieter environment with enhanced aesthetic appeal. While these changes generally improve conditions for relaxation and leisure, they might limit activities requiring open spaces, sunlight, or diverse ecosystems. Careful planning and management can balance these effects to cater to varied visitor preferences.

Discussion

The Norway maple (*A. platanoides*) is a deciduous tree native to temperate regions of North America. It grows up to 20 m tall and has sharply toothed leaves. The flowers are small, yellow, and appear in spring. It prefers moist soils and shady areas. Due to its attractive appearance, *A. platanoides* is often used as an ornamental plant in gardens and parks around the world. The tree is large and fast-growing. It is the most widespread native maple in Europe, with a natural range stretching from Greece to the Ural Mountains in Russia. It is widely planted as a shade tree and for ornamental purposes, and is highly valued for its colourful autumn foliage and resistance to urban conditions. The wood is used for furniture, decorative items, joinery, and - when it has a wavy texture - for stringed instruments. The additional roots make the tree useful for erosion control and slope stabilisation. Norway maple grows well in deep, fertile, and moist soils, but it can grow in a variety of soil conditions. The tree also tolerates shade, drought, and pollution. It is often found in mixed stands with both coniferous and deciduous trees, and grows at altitudes from sea level to 1,400 m. It grows best in soils that are well drained and have a slightly acidic pH. It tolerates soil exposure and liming. It does not tolerate low soil nitrogen content, high evaporation or prolonged drought, and is rarely found in acidic soils (pH around 4) (Nowak et al., 2008). The pollination of flowers occurs through insect activity, and these flowers typically emerge when the tree reaches an age of 25 to 30 years. The species is commonly found at the base of hills, where it benefits from surface runoff and groundwater flow. Additionally, it flourishes at higher elevations that receive adequate rainfall. The germination process is rapid, and the tree is capable of growing in shaded environments, even beneath a dense canopy. However, as it matures, it becomes increasingly reliant on light. During the initial decade of growth, the tree exhibits an average height increase of approximately 1 meter per year. Due to its expansive crown, it tends to overshadow and inhibit the growth of slower-growing competitor species. Under optimal conditions, lifespan of *A. saccharinum* can exceed 250 years. Throughout Europe, this species is typically found in moist and fresh habitats within both coniferous and deciduous forests. In temperate continental mixed forests, it may co-dominate alongside other broadleafed species, such as the oak (*Quercus robur*) and the small-leaved lime (*Tilia cordata*) (Bosco et al., 2015; Nguyen Trong et al., 2020). The species is notable for its aesthetic appeal, vibrant foliage, and expansive canopy, in addition to its resilience in urban environments. Norway maple is widely used as an ornamental tree, shade tree, and for street greening. Its ability to regrow vigorously after pruning makes it suitable for use as a hedge.

In its natural habitat, the Norway maple typically does not experience significant disease issues. However, in urban environments, this species, along with other maple varieties, may be susceptible to a range of diseases. These health challenges are often exacerbated by a combination of stressors, including pollution, alterations in terrain, and soil compaction. A significant pathogen is *Cryptostroma corticale*, prevalent in North America and Central Europe, primarily affecting sycamore maple (*Acer pseudoplatanus*). It poses a serious threat to the Norway maple, as the latter experiences considerable damage during hot and dry summer conditions. The Asian long-horned beetle, *Anoplophora glabripennis*, is a sizable wood-boring beetle indigenous to various Asian countries, including Japan, Korea, and China. Its larvae tunnel through and feed on the cambium layer of the bark, targeting both healthy and stressed trees, ultimately leading to the death of the host. The species in question has significant economic, environmental, and aesthetic implications for various deciduous trees, particularly within the United States. However, more recently in Europe, certain species have become particularly vulnerable, notably the Norway maple and other members of the genus *Acer*, which are among the primary species affected. Fungi belonging to the *Rhytisma* genus infect maple leaves, resulting in the formation of black spots on their upper surface. Fungi belonging to the genus *Verticillium* infect ornamental and garden plants via the root system, specifically targeting the water-conducting tissues, which leads to blocking the movement of water to the leaves (Wurzbacher et al., 2016). *Cameraria ochridella*, commonly referred to as the horse-chestnut leaf miner, is primarily recognized for its significant impact on the European chestnut (*Aesculus hippocastanum* L.). However, it also poses a threat to the Norway maple, which partially shares the ecological niche of *C. ochridella* (Barredo et al., 2015). In the mid-twentieth century, this species was extensively cultivated in the United States as a substitute for the American elm (*Ulmus americana*), which had been decimated by Dutch elm disease. Nevertheless, due to its rapid growth, dense canopy, and shallow root system, it has emerged as an invasive species, leading to a decline in the abundance and diversity of native flora and disrupting the structural integrity of forest ecosystems. Its invasion has been particularly pronounced in mixed deciduous forests, especially in disturbed regions of eastern North America, necessitating the implementation of mechanical or chemical control strategies in certain instances (Reinhart et al., 2006). The Norway maple is often regarded as one of the most problematic invasive species. Its prolific seed production and capacity to thrive in environmentally challenging conditions contribute to its prevalence in urban environments. In Ukrainian cities, the share of all green spaces accounted for by this tree ranges up to 35%. And despite its invasive status, it is argued that a rapid decline in the maple population could worsen the unfavourable environmental situation in the city (Matkovskaet al., 2019; Vykhor & Prots, 2013).

Therefore, study of ecological and morphological features of *A. platanoides* is very relevant, and in Ukraine was carried out in such industrial cities as Zhytomyr and Donetsk prior the Russian full-scale invasion (Kornienko et al., 2019; Matkovska et al., 2019). The papers describe urban ecosystems and their transformation under the anthropogenic factors impact. This study examines the effects of the anthropogenic environment in urban areas on plant organisms, focusing on the physiological and morphological alterations they undergo. The research identified a significant level of anthropogenic stress, as evidenced by the analysis of vibration and acoustic noise along roadways, the concentration of heavy metals in soil, and the presence of air pollutants in the examined regions. A strong correlation was established between the fluctuating asymmetry index of the leaf blades of *A. platanoides* and both the viability index and the degree of noise pollution along motorways. Additionally, the primary indicators of mechanical stability in *A. platanoides* were analyzed. The findings indicate that young trees (aged 5–7 years) and those exhibiting low viability scores, particularly as they approach critical age in urban environments, are at the greatest risk of fracture. According to the results of the research, *A. platanoides* is a mechanically stable species in industrial cities. To increase mechanical resistance, it is recommended to carry out sanitary pruning to narrow the crown (shortening long horizontal branches). Growing along motorways, with proper care, the species is resistant to the complex effects of traffic and is suitable for planting in the first row along roads (Kornienko et al., 2019). Our study has confirmed that the population of Norway maple in an industrial city, located in a park area, is thriving in favorable ecological conditions. Among the individuals of this species, none were recorded with vitality scores of 4 (poor condition) or 5 (very poor condition - dying trees) on the vitality scale.

Conclusions

Today, the Norway maple is widely used around the world for landscaping lawns, streets, and city parks. This species is notable for its attractive appearance, vibrant autumn colors, and adaptability to various conditions. However, it is also regarded as one of the most dangerous invasive species, posing a threat to local flora due to its prolific seed production and ability to thrive in environmentally unfavorable areas. However, its abundant seed reproduction and ability to thrive in environmentally unfavorable conditions makes its widespread use somewhat controversial. Concurrently, the rapid decline in the population of ash maples is believed to exacerbate the adverse environmental conditions in urban areas. Studying the ecological and morphological characteristics of this species allows for a more in-depth study of these issues. We documented 113 individuals of *A. platanoides* within the recreational area of the Oles Honchar Dnipro National University Botanical Garden, representing 15.5% of the overall tree population across all species. The distribution of Norway maple was not uniform, as these trees predominantly inhabited the central part of the research area. The analysis of the trees in the research area, based on trunk height, revealed that the most numerous groups were those with trunk heights ranging 4.1 to 8 m and 16.1 to 20 m, comprising 24 and 23 individuals, respectively. The group of trees with the tallest trunks (24.1 to 28 m) included 8 individuals.The most numerous group, consisting of 41 trees, included the thinnest plants in the population, each with a trunk diameter of less than 10 cm, and only 6 plants had a trunk diameter greater than 50 cm. There was a linear relationship between the height and trunk diameter of the studied *A. platanoides* individuals; as plant height increased, the diameter of the trunk also increased. This relationship was statistically significant for trees with vital state of 1 and 2 ($P = 0.012$ and $P < 0.001$, respectively). The tallest representatives of the Norway maple, reaching heights of over 25 meters, typically had trunk diameters ranging 45 to 57.3 centimeters, while the shortest representatives, measuring up to 5 meters, had trunk diameters of up to 5 centimeters. The tallest recorded plant had a trunk diameter of 57.3 centimeters. The vast majority of the trees (94 representatives) were characterized by a vital state score of 2, indicating good condition. This group included plants that exhibited the greatest variation in morphometric parameters. Nearly the same number of plants had vital state of 1 (healthy trees) and 3 (satisfactory condition of trees), with 10 and 9 plants, respectively. Plants with a vital state of 1 were characterized by the highest trunk height and diameter, exhibiting relatively low variability. Vital state of 4 and 5 were not recorded in the study area. The total vital state index of the studied population of *A. platanoides* in the DNU Botanical Garden park zone was 97.6%, indicating that the plants are healthy. This suggests that the examined plants are thriving in favorable environmental conditions.

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